ADAMAS
ADVANCED DIAMOND ASSEMBLIES

1st Workshop GSI 16 – 18 December 2012

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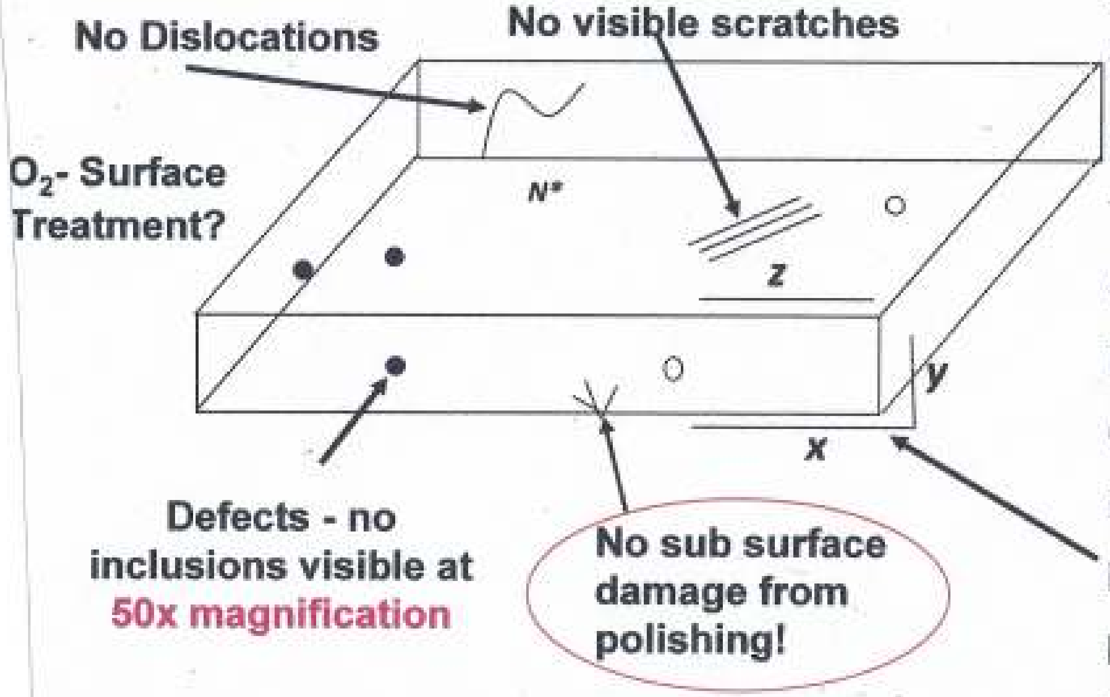
Advantages Synthetic Diamond Detectors

- Unique Properties
- Intrinsic ,Diamond is an insulator at room temperature
  Electron and hole higher than silicon ,sub nanosecond
- Diamond RAD HARD 2 orders better10.17p/cm2
- Comparison to Silicon -N-type FZ and N-type Oxygenated10.15p/cm2
- P type Silicon benefit,150um,from charge multiplication10.16p/cm2
- Even thinner100um P-type pixels at CERN CLIC/40um target.
- Micron's NASA Mission: Solar Probe Plus large 10 um thick detector with a uniformity of 0.3um,diamond films on silicon would be similar
- High refractive index compared to glass 2.4-1.5,perfect for gems
- Extreme Surface Hardness ideal for cutters/ drills/ sanders
- Heavy Ion detection , 1 nanosecond,10.10 p/cm2 survival,Si.10.8p/cm2
- High Thermal Conductivity benefits electronics power dissipation
- Solar Blind , sensitive in deep ultraviolet
- Low dielectric low capacitance load benefits preamplifier noise

Disadvantages Synthetic Diamond Detectors

- Disadvantages:
  - Small Size Single Crystal Diamond 5mm x5mm difficult to grow.
  - Little or NO IMPROVEMENT in size in past decade
  - Cutting Difficult, laser essential.
  - Polishing an art form, preparation, motion, materials.
  - Metal Film technology, interfaces,
  - Very expensive single crystal
  - Single Crystal Detector Grade requires << ppm nitrogen
  - Intrinsic Polysilicon (Ohmic) Boron doped (Shottky) cost effective
  - Pumping effect: never irradiated in virgin state: moderate irradiation fluence, signal output charge distance increases
  - Long term reliability REQUIRED, to replace BEST EFFORT.
  - Commercial Warranty important ,12 months minimum.
  - Current Designs requires high voltage to collect charge
  - No N-type (DONOR) diamond on the market.

Single and Polycrystalline Diamond Detector Specification



Size of Substrate - +- 0.1mm

Thickness - 50 micron ± 15 micron

Surface Roughness < 5nm

Twin Defects - none

Grain Size - >100 microns (Poly)

N impurities < 5ppb typical

Cracks – none

Edge chips- none > 20 microns

Parallelism -within thickness level

Metal Contamination - < 1ppb

Voids or Pits – None

SP^2 level - not detectable

Charge Collection Efficiency 40% for poly and 96% for Single Crystal

Properties and Cost of Various Types of Diamond Substrates

Properties	Graphite	SC Diamond	Polycrystalline / Electronic	BD Diamond	Thermal Grade D	Thermal DLC
SP2	100%	None, SP3 only	None, SP3 only	SP3 + B	very little	5-10%
Fabrication	Natural	PECVD	PECVD	PECVD	PECVD	ARC/PECVD
Grain Size	-	Single Crystal	100microns	~50 microns	~ 50 microns	Amorphous
Collection Efficiency		100%	60%	-	~2-10%	-
Electron Mobility	-	4500	2500	-	-	-
Breakdown	-	4 MV/cm	0.7	> 0.7	>0.7	-
Cost /mm^3	-	£30/mm^3	£3.0/mm^3	25p/mm^3	from 25p/mm^3	8-25p/mm^3

Future Technology

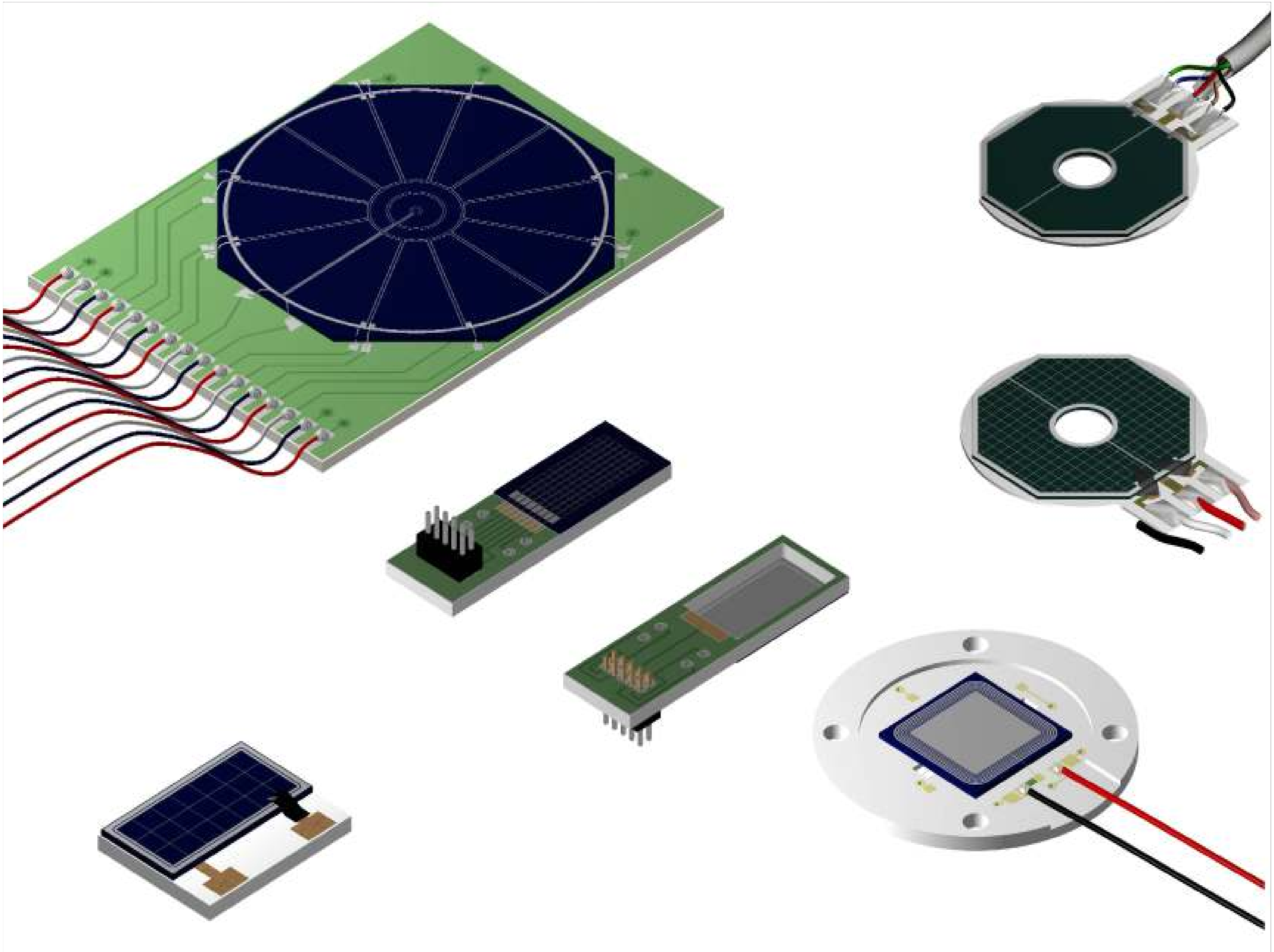
- Ion Implantation at Micron
- N Type Lithium/ arsenic/ phosphorus implant candidates for P Type Boron doped diamond
- Plasma Trenching/ Pillars/ 3D Monitors
- Silicon development with plasma trenching
- Pixel Imagers with diamond for IMRT/Neutron Gun applications
- Flip chip bump bonding, development with silicon/CERN CLIC
- Passivation would benefit operational reliability and warranty

Packaging/DDL and Micron Ceramic range in stock

- Ohmic Contacts to diamond/Sputtered Aluminium
- Solderable Ti/Pt/Ag or bondable Ti/Pt/Au
- Underbump metallising for silicon solder ball bumps Al/TiW/Cu
- E Beam multiple crucible permits up to 4 metals in sequence

Packages

- Packages acquired from the BAE/ E6 buy out
- Current Diamond Small Size limits using wide range of silicon UHV Ceramic package designs
- Diamond film on silicon via iridium would permit 4 inch and 6 inch technology
- Use of 6 inch diamond a dream or not?



Silicon Dosimeters

- Teledyne USA market a dosimeter using Micron Silicon detectors
- Qualified to K level requiring 125C operation
- Military standard
- Used on satellites but marketed for airlines where ,radiation high, medical applications

Diamond detector option will be included

SPACE QUALIFIED DIAMOND DETECTORS

Class H hybrid, is standard Military grade

1. Electrical Tests	Group A Tests at 25C	100%
2. Visual Examination	MIL-STD-750, Method 2073	100%
3. Wire Bond Evaluation	MIL-STD-883, Method 2011	10 (0) or 20 (1) wire (twenty wires, 1 failure)

Micron does item 1 above on all detectors before they are shipped.
Hi-Rel will do item 2 above. They do it all the time.
Hi-Rel, Teledyne, or Micron can all do item 3. Micron should provide a few electrical rejects from the same metallization run for 10 or 20 wire bond samples.
That is all there is for MIL level Element Evaluation.

NOTE: CRaTER, RBSP, MMS, and RPS all require class H hybrids.

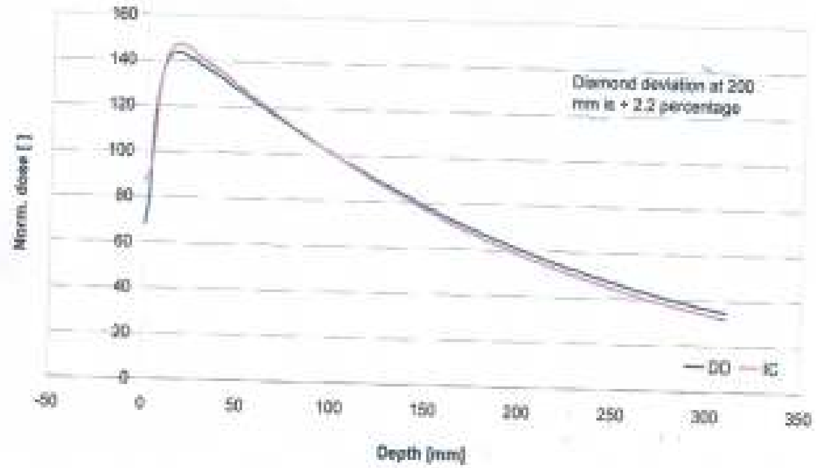
Class K is critical Space Level
Dosimeter Element Evaluation for class K starts the same as class H but adds the following eight (8) steps:

NOTE: These are all the same 10 samples.

4. Temperature Cycling	MIL-STD-883, Method 1010, Condition C	10 (0)
5. Mechanical Shock or	MIL-STD-883, Method 2002, B, Y1	10 (0)
Constant Acceleration	MIL-STD-883, Method 2001, 3000g, Y1	10 (0)
6. Interim Electrical	Group A Tests at 25°C	10 (0)
7. Burn-in	MIL-STD-883, Method 1015, 240 Hours, 125°C	10 (0)
8. Post Burn-in Electrical	Group A Tests at 25°C	10 (0)
9. Steady State Life	MIL-STD-883, Method 1005, 1000 Hours, 125°C	10 (0)
10. Post Life Test Electrical	Group A Tests at 25°C	10 (0)
11. SEM Inspection	MIL-STD-883, Method 2018	10 (0)

Micron or Hi-Rel will do item 4.
Hi-Rel or Micron can do item 5.
All 10 parts must be done by Micron for item 6, 7, 8, 9 and 10.
Hi-Rel will do item 11.

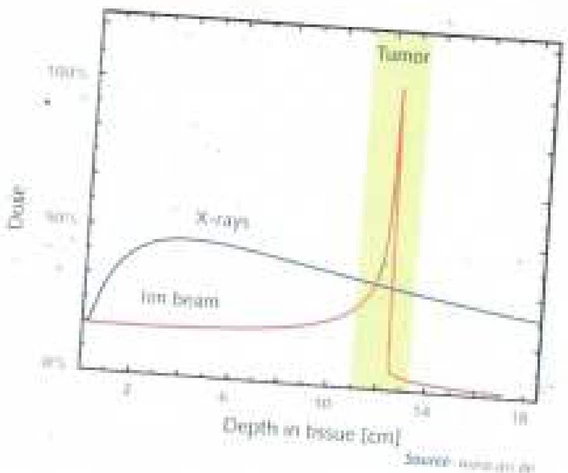
Industrial Application Radiotherapy Beams IMRT (comparison diamond v ion-chamber Dose v Depth)



Industrial Application Radiotherapy Beams CPT

Charge Particle Radiotherapy High Energy Beams

It is estimated that 15% of all patients treated with conventional radiation would receive a better treatment with CPT.



Tumour depth up to 30cm

Proton beam 200MeV
Carbon beam 4800MeV

Can now treat previously in-operable cancers
Due to high accuracy of placement and Low Dose to surrounding tissue

High Temperature Operation

- Diamond capable of operating to 1000C
- Band gap reduces with increasing temperature
- Valence band comes into play
- Hole collection and resolution can improve whilst leakage currents are low

  Japan 1997 operated Shottky Barrier Diamond at 300C
- UK 2011,DDL Ohmic Diamond operated at 220C

  Schlumberger/JPL/Caltech neutron probe for Mars/ Venus requires 500C at 100 atmospheres
- Micron plan to develop high temperature operating diamond detectors to replace He3 for reactor monitoring but in competition with boron carbide semiconductor where large active areas are available

Ohmic vs Schottky Contacts on Diamond

$Bv = Mw - Xe$ (n-type)

$Bv = Mw - (Xe + Eg)$ (p-type)

Mw :- is metal work function

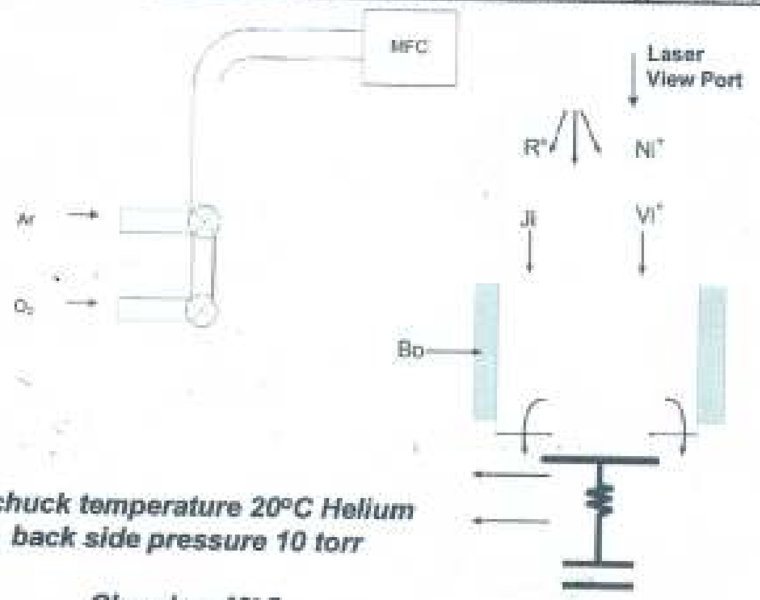
Xe is the semiconductor electron af

Eg is the semiconductor band gap

For p type if Bv is positive contact is Ohmic (injecting), if negative contact is Schottky (rectifying). Forming Ohmic contacts on such a wide band gap material is difficult as metals have too low a work function. But with surface modification and increase p+ surface concentration (via B^+ implantation) will allow charge tunnelling to be achieved more easily. Diamond Carbide formation also helps form Ohmic contacts and improves adhesion.

Schottky contacts are less reliable on wide band gap devices. With diamond the surface must be H– terminated for Schottky contacts which is less stable than O- terminated. Some workers have no problem with this particularly with lower grade material.

Plasma ICP for Diamond Thinning and Damage Removal



E-chuck temperature 20°C Helium back side pressure 10 torr

Chamber 40°C

20 mtorr pressu

2000 watts coil p

200 watts substr

50 sccm Oxygen

30 sccm Argon fl

Diamond substra hard baked resist wafer to reduce s contamination an with O* radical qu Back to back rf to particle depositio

Aim is to remove and not to introdu surface roughnes

Test facility Strontium 90

- Class 5 28.8 years 97 bq
- Collimated delivers Beta electrons
- Lack of gamma ray decays
- Gamma 90 decays
- Beta emits electrons 0.55 MeV / 2.2MeV
- Suitable for all diamond thicknesses to a maximum of 2mm thickness

Diamond Detector Sizes

- Single Crystal 4mm x 4mm
- Polycrystalline Diamond   10mm x 10mm
- Polycrystalline Diamond   15mm x 15mm
- Polycrystalline   20mmx 20mm
- DEVELOPMENT
- 100mm /150nm Diamond Layer 10um-50um
- Diamond on Diamond /Silicon/Iridium
- Polycrystalline Diamond 150mm   Ideal

Neutron Detectors

- Low Quality Diamond maybe fine for converter applications
- Diamond Efficiency is subject to design 5% - 70%feasible
- NEW Semiconductor creating interest: Research Universities
- BORON CARBIDE SEMICONDUCTOR
- 5 years to a working device
- Hetero Junction on silicon, 40mm x 40mm size
- Count rate 600 neutrons/sec/cm2 Mobility 50 -550,not fast
- 40 um depletion 90%efficiency ,2um 12%,
- Band gap 1.5eV to 3.7eV,depending on hydrogen content
- Operation to 350C,retaining low dark current
- Low voltage operation 0-10 volts
- Excellent neutron signal with spaced 2 MeV energy peaks
- Sizes 4cm x cm contacts titanium-silver blocks being built
- Devices improve initially with radiation reduce high levels
- Applications: Nuclear Forensic/ Nuclear Asset Stewardship

SNS-NGREM Neutron Detector

Data Sheet for Spherical Neutron Detector Type SNS-NGREM

The NGREM detector is designed for use in a portable monitor: its light weight gives it a significant advantage when used in confined spaces or when it is necessary to climb ladders etc while carrying it. Although it does not have the best energy response its low weight makes it the instrument of choice for use in the UK and on UK nuclear submarines. The NGREM has over 3 times the sensitivity of the original Leake design that has been in continuous operation since it was developed at Harwell in 1968. The new design replaces the original cadmium shield by one made of boron loaded polyethylene. The use of MCNP modeling has enabled the diameter of the inner moderator (i.e. that part within the shield) to be increased and the quantity of neutron absorbing material in the shield to be reduced and both of these increases the sensitivity. The original SP9 detector (33 mm outside diameter) has been retained giving an increase in neutron sensitivity of 3.1 times.

Reference: J.W. Leake, T. Lowe and R.S. Mason, *'Improvements to the Leake Neutron Detector I'*, Nuclear Instruments & Methods in Physics Research, **A 519** (2004) 636 – 646.

Energy Response

The neutron energy response is essentially unchanged from the original design. The design aims to provide a response that is proportional to the Ambient Dose Equivalent H*(10) as defined by ICRP 74. The design overestimates H*(10) in the region around 5 keV by a maximum of 8.3 (compared to 1 MeV) but this is a deliberate compromise between weight and overestimation. The responses at thermal energy (0.025 eV) and 10 MeV are over half (0.53) of that at 1 MeV. In most situations the proportion of ambient D.E. is small in the 5 keV region and so in general the overestimation can be kept below a factor of 2, depending upon the calibration energy used. The calibration factor can be varied to optimize measurements in known spectral fields or can be set to give a fail safe (i.e. over-estimate) for unknown spectral situations. Calibration at the UK National Physical Laboratory at 33 keV, 565 keV and 2500 keV shows good agreement with the computed MCNP values.

Sensitivity

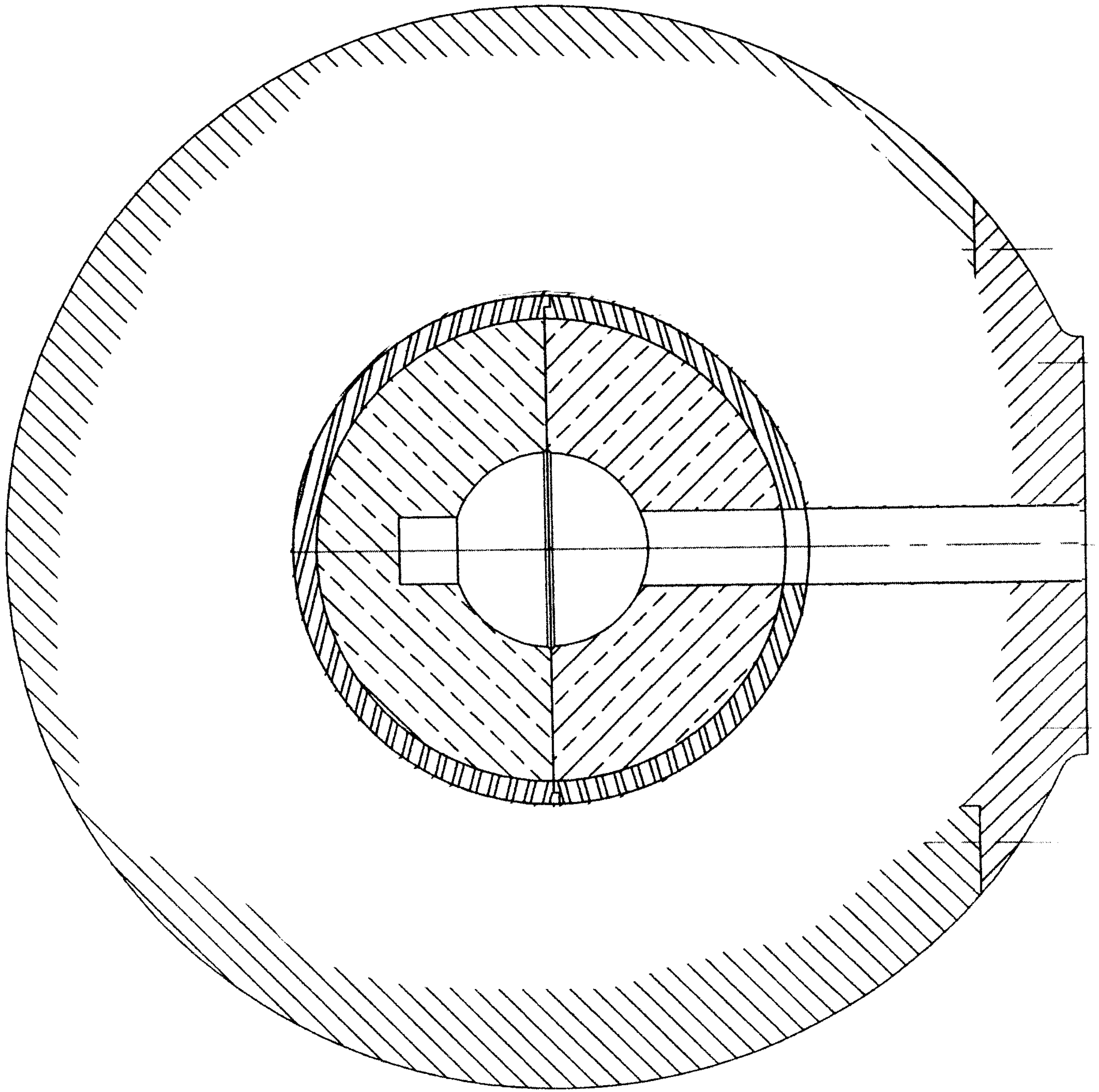
The detector responds to neutrons of all energies from 0.025 eV (thermal) to 10 MeV (with a rapidly reducing sensitivity thereafter). The nominal sensitivity at 1 MeV is 2.66 counts per nSv i.e. 0.74 counts per sec per μSv/h.

Polar Response

The spherical geometry of the detector guarantees that an excellent polar response is obtained. There will be a variation in the region of the ^{3}He counter connector but most instruments are designed so that the electronics/ batteries are located in this area.

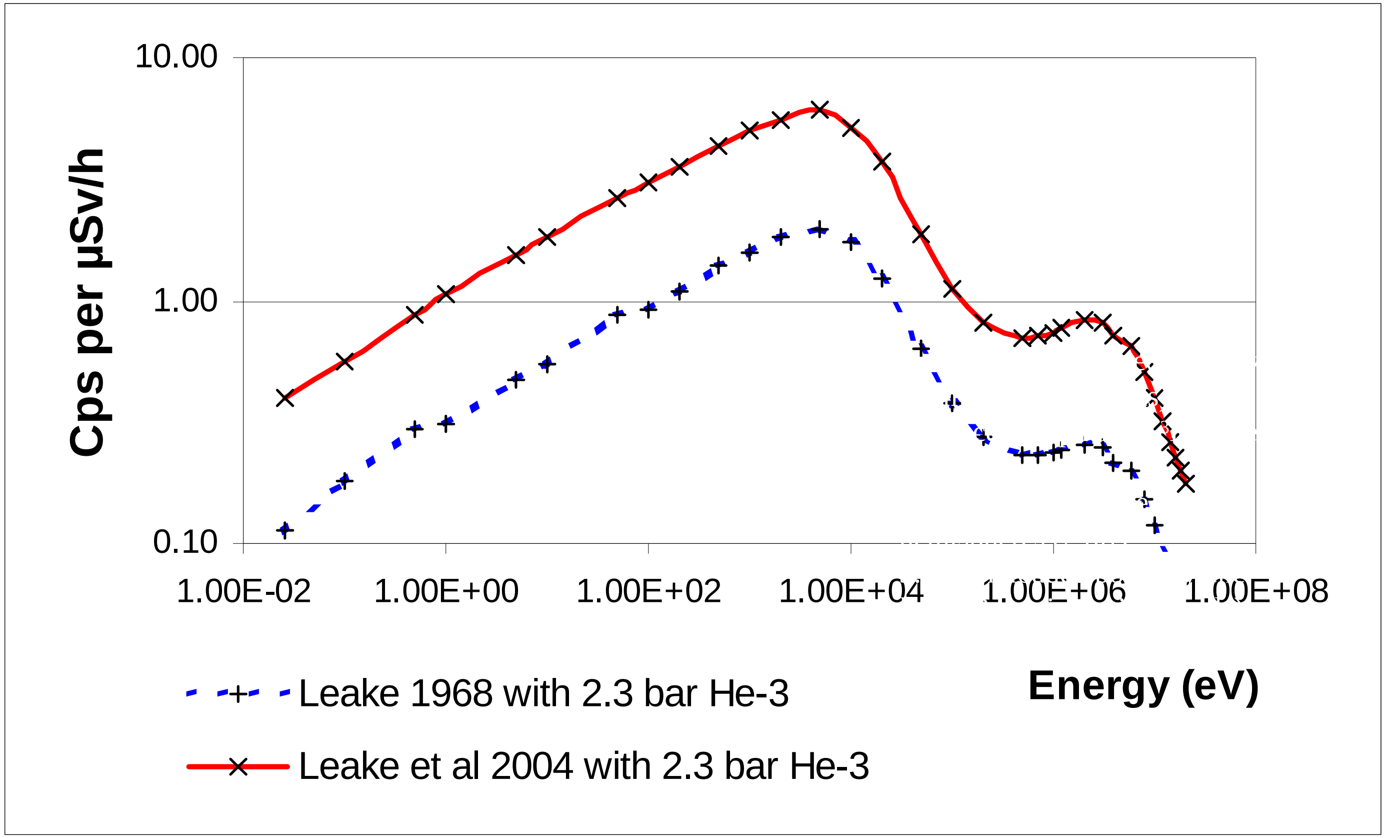
EMC Response

The EMC response will depend on the electronics used. If used as part of an integral instrument then refer to supplier's specification. If the detector is to be operated with separate electronics then refer to SNS for details of tests performed.



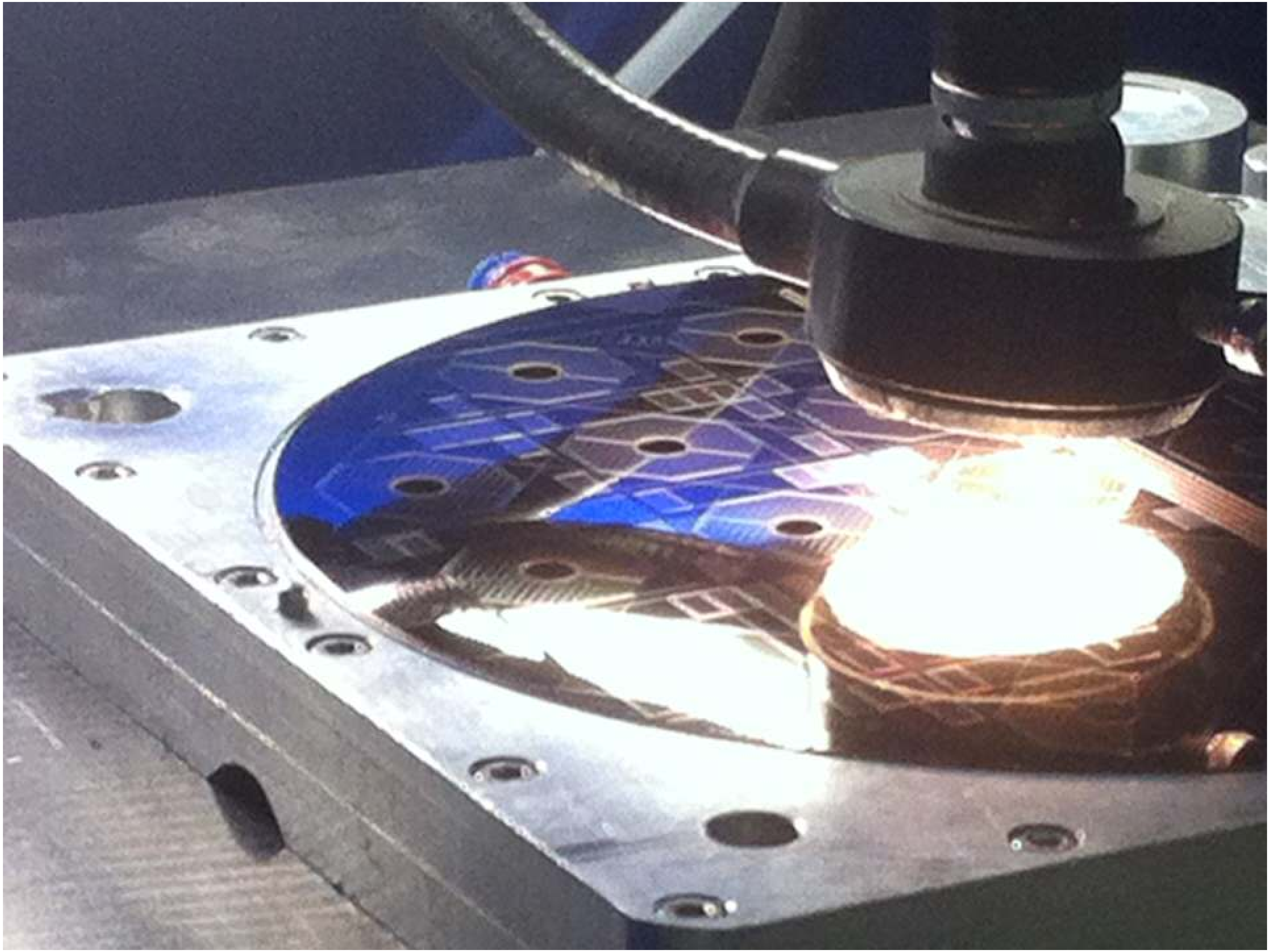
Cross-section of detector showing (from centre outwards)

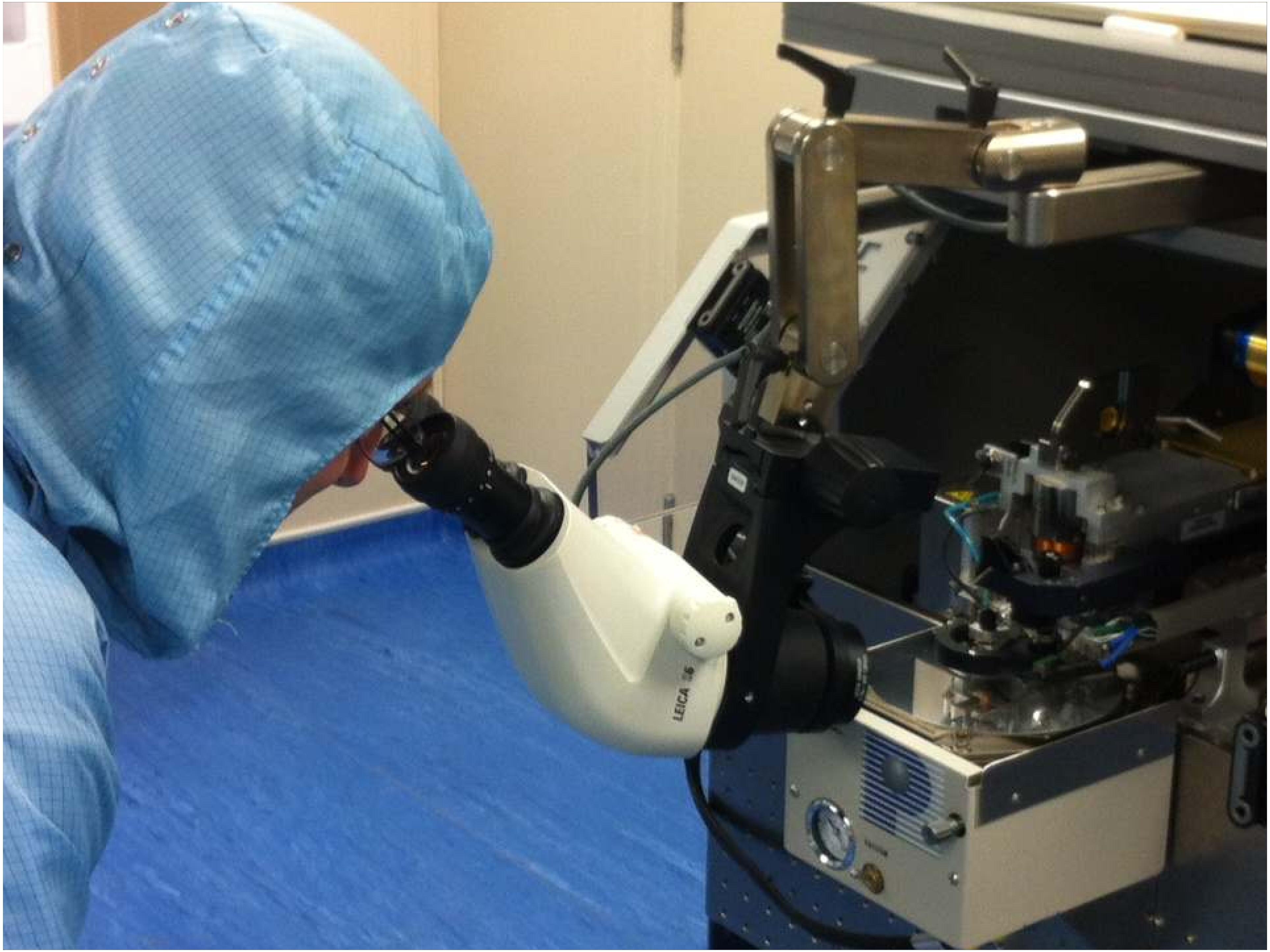
1. Space for spherical ^{3}He filled counter
2. Inner polyethylene hemispheres (2 off)
3. Boron loaded polyethylene layer (2 hemispherical shells)
4. Outer polyethylene sphere

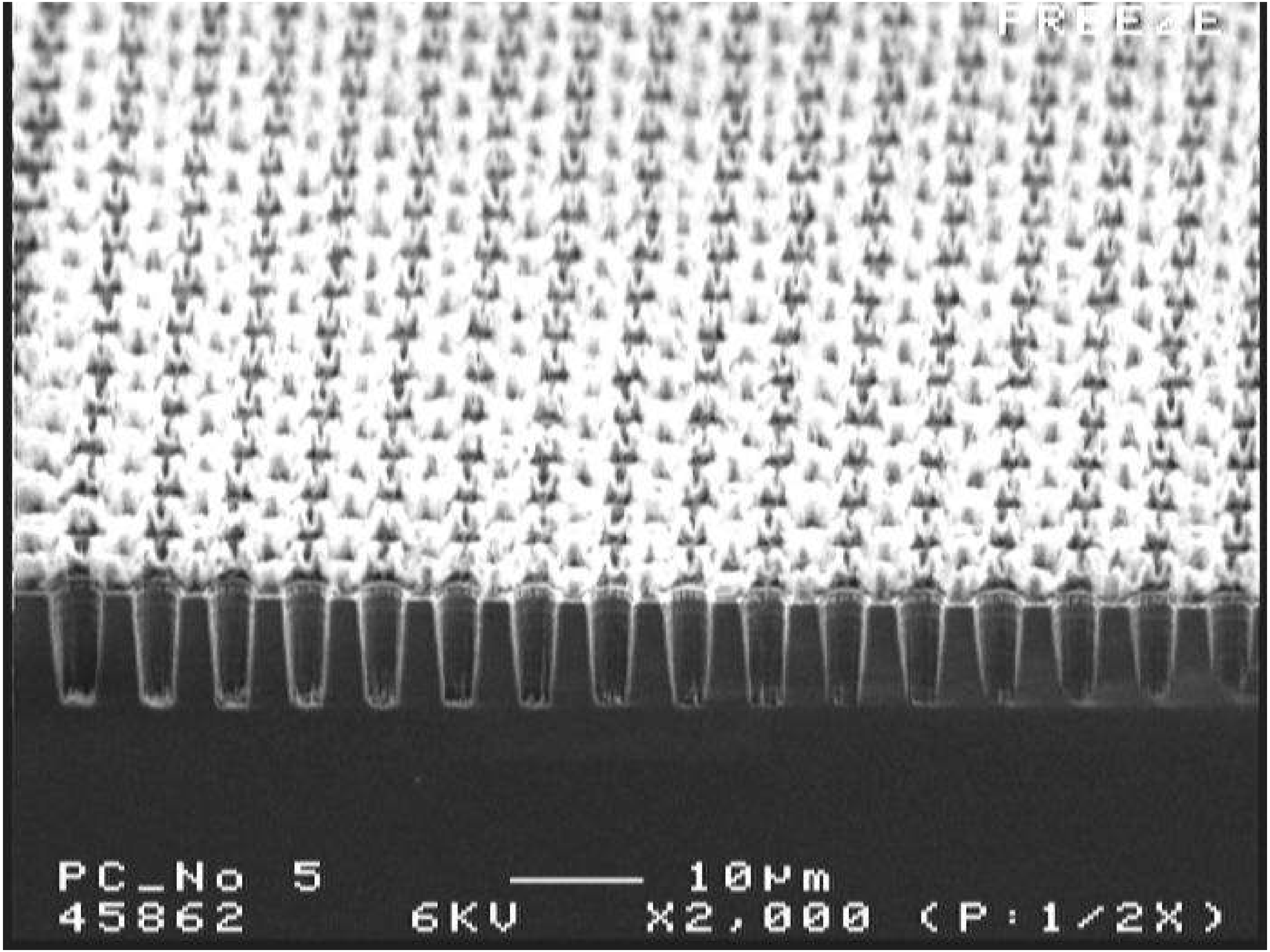


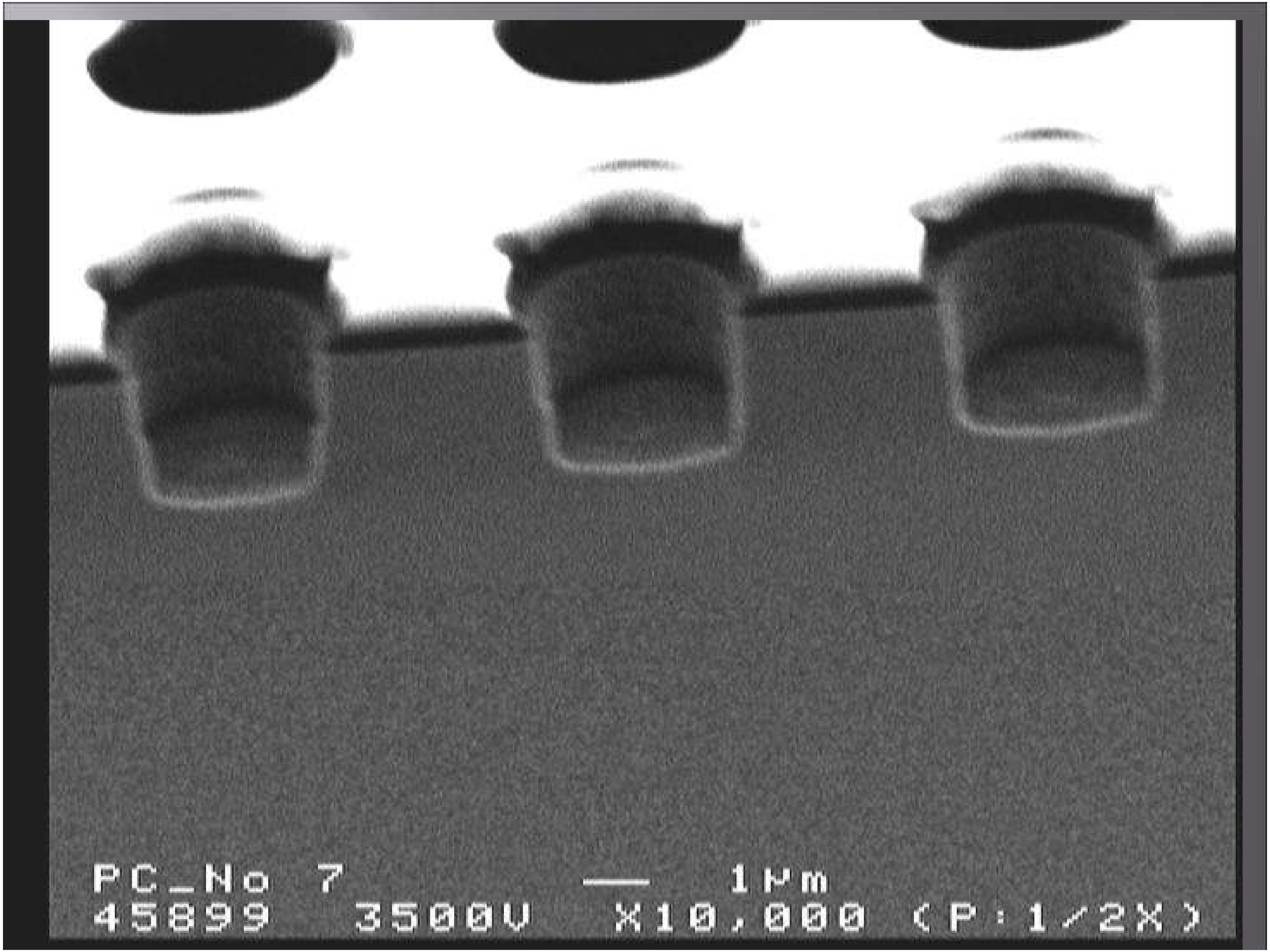
10.00
1.00
0.10
Cps per µSv/h
1.00E-02
1.00E+00
1.00E+02
1.00E+04
1.00E+06
1.00E+08
Energy (eV)
Leake 1968 with 2.3 bar He-3
Leake et al 2004 with 2.3 bar He-3

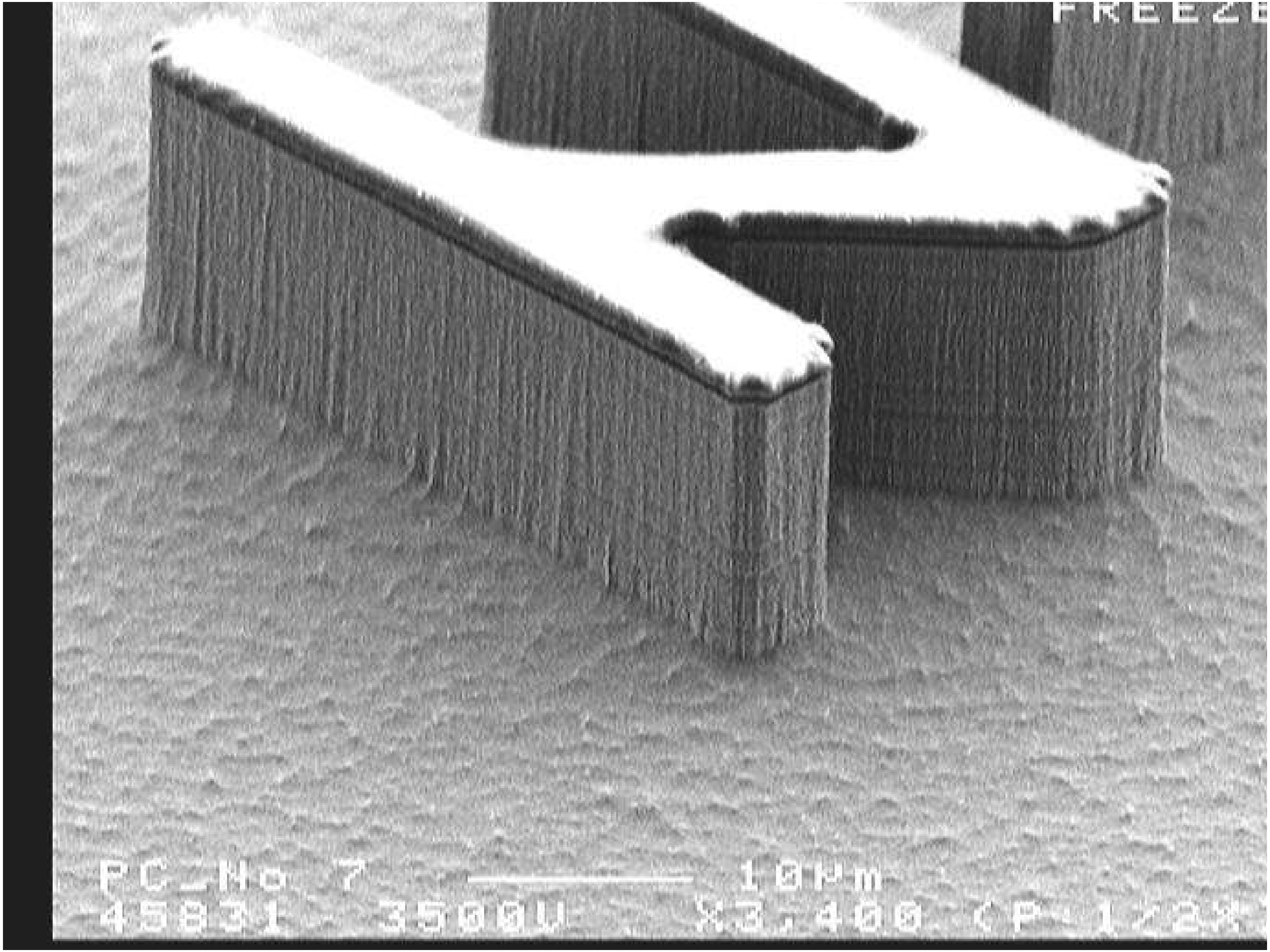

01XPA
02XPA
Danger




LEICA


FREEZE
PC_No 5
10μm
45862
6KV
X2,000 (P:1/2X)


PC_No 7
1μm
45899 3500V X10,000 (P:1/2X)


PC_No 7
10µm
45831 3500V
X3,400